

AT89C51 In-Circuit Programming

This application note illustrates the in-circuit programmability of the Atmel AT89C51 Flash-based microcontroller. Guidelines for the addition of in-circuit programmability to AT89C51 applications are presented along with an application example and the modifications to it required to support in-circuit programming. A method is then shown by which the AT89C51 microcontroller in the application can be reprogrammed remotely, over a commercial telephone line. The circuitry described in this application note supports five volt programming only, requiring the use of an AT89C51-XX-5. The standard AT89C51 requires 12 volts for programming.

The software for this application may be obtained by downloading from Atmel's BBS: (408) 436-4309.

General Considerations

Circuitry added to support AT89C51 in-circuit programming should appear transparent to the application when programming is not taking place.

\overline{EA}/VPP must be held high during programming. In applications which do not utilize external program memory, this pin may be permanently strapped to V_{CC} . Applications utilizing external program memory require that this pin be held low during normal operation.

RST must be held active during programming. A means must be provided for overriding the application reset circuit, which typically asserts RST only briefly after power is applied.

\overline{PSEN} must be held low during programming, but must not be driven during normal operation.

ALE/\overline{PROG} is pulsed low during programming, but must not be driven during normal operation.

During programming, AT89C51 I/O ports are used for the application of mode select, addresses and data, possibly requiring that the controller be isolated from the application circuitry. How this is done is application dependent and will be addressed here only in general terms.

Port Used for Input

During programming, the controller must be isolated from signals sourced by the application circuitry. A buffer with three-state outputs might be inserted between the application circuitry and the controller, with the buffer outputs three-stated when programming is enabled. Alternatively, a multiplexer might be used to select between signal sources, with signals applied to the controller by either the application circuitry or the programmer circuitry.

Port Used for Output

No circuit changes are required if the application circuitry can tolerate the state changes which occur at the port during programming. If the prior state of the application circuitry must be maintained during programming, a latch might be inserted between the controller and the application circuitry. The latch is enabled during programming, preserving the state of the application circuitry.

An Application Example

The AT89C51 application shown in Figure 1 is an implementation of a moving display. This application was selected for its simplicity and ability to show graphically the results of in-circuit reprogramming. The text to be displayed is programmed into the controller as part of its firmware, and cannot be changed without reprogramming the device.



8-Bit Microcontroller with Flash

Application Note

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The displayed text is presented in one of two modes selected by the four-position DIP switch. In the first mode, one character at a time enters the display from the right and moves quickly to the left through each element of the display to its final position in the assembled message. In the second mode, the message moves through the display, from right to left, with the display acting as a window onto the message. This mode is familiar as the method often used in displays of stock prices.

The output consists of four DL1414T, four-digit, 17-segment alphanumeric displays with integral decoders and drivers. This yields 16 total display elements, each capable of displaying digits 0-9, the upper case alphabet, and some punctuation characters. The displayable character codes are ASCII 20H-5FH.

A power-on reset circuit and a 6-MHz crystal oscillator complete the application. Neither external program memory nor external data memory is used.

Modifications to the Application to Support In-Circuit Programming

Figure 2 shows the application modified for in-circuit programming.

It is assumed that the programmer, when inactive, will neither drive nor excessively load the application.

Since the application does not use external program memory, \overline{EA}/VPP on the controller is connected to V_{CC} . This meets the requirement for programming.

The reset circuit has been modified by the addition of two transistors, which allow RST on the controller to be forced high by the programmer.

\overline{PSEN} and $ALE/PROG$, unused in the basic application, are under the direct control of the programmer.

Programming requires programmer access to all of the four AT89C51 I/O ports, as documented in the data sheet. The programmer is connected directly to those controller pins which are unused by the application, while access to pins used by the application requires special treatment, as explained in the following paragraphs.

The least significant four bits of the address generated by the programmer are multiplexed onto port one of the controller with the data from the DIP switch. Note that the four resistors added at the switch are not required in the basic application, since the AT89C51 provides internal pull-ups on port one.

During the normal operation of the application, controller ports zero and two provide data and control signals (respectively) to the displays. During programming and program verification, the programmer asserts control of port zero and part of port two. The programmer is connected to ports zero and two without buffering, since, when inactive, its presence does not affect the normal operation of the application.

A transparent latch has been added between port two of the controller and the display control inputs. The latch holds the display control signals inactive during programming, which eliminates erratic operation of the displays due to programmer activity on ports zero and two. No isolation of the display data inputs is required, since data applied to the inputs is ignored when the control signals are inactive.

The AT89C51 reset circuit, input multiplexer and output latch are controlled by a single signal generated by the programmer. During programming, reset is asserted, the multiplexer switches inputs, and the latch freezes the display control lines.

To ensure that the display control lines are in a known state before they are latched, an AT89C51 external interrupt is used to allow the programmer to signal the application before asserting reset. The application firmware responds to the interrupt by displaying a message and deactivating the display control lines.

After programming, when reset is deasserted, the controller ports are high as the latch becomes transparent. Since the display control inputs are inactive high, the display contents are not disturbed until the new program writes the display.

Although not essential to this application, it might be imperative in some applications that the state of the peripheral circuitry not be disturbed during programming.

The Programmer

The programmer (Figure 3) generates the addresses, data and control signals necessary to program the AT89C51 embedded in the application.

The programmer circuitry consists of an AT89C51 and an RS-232 level translator. The controller runs at 11.0592 MHz, which allows the serial port to operate at a number of standard baud rates. A Maxim MAX232 line driver/receiver produces RS-232 levels at the serial interface while requiring only a five volt supply.

Many of the signals generated by the programmer are connected directly, without buffering, to the AT89C51 in the application. These signals, when inactive, are not three-stated, but are pulled high. The AT89C51 has internal pull-ups of approximately three Kohms on ports one, two and three. Because port zero does not have internal pull-ups, external pull-ups of ten Kohms have been added to permit proper operation of program verification mode. The sample application operates correctly in this environment. If required for compatibility with an application, programmer signals may be buffered with three-state buffers similar to the 74xx125.

The AT89C51 in the programmer does not utilize external program or data memory, which would require sacrificing needed I/O pins. This requires that program code and I/O buffers be kept small enough to fit in on-chip memory.

Remote Programming Over a Commercial Telephone Line

The programmer and display application described previously are connected to a phone line via a modem at a remote site. Using a personal computer with a modem, a user can upload a new program containing a new message, which is programmed into the AT89C51 embedded in the application. When programming is complete, the application executes the new program, which displays the new message.

Local Station

The local station in the test configuration consists of an IBM PC AT-class computer connected to a Hayes-compatible, Prometheus 1200 baud modem. The modem was selected because it was inexpensive and available. A faster modem may be used if desired, although once the file transmission time is reduced below one minute, further reductions in transmission time do not further reduce connect time charges. A possible advantage to higher transmission speeds is the automatic error detection and correction available in some high speed modems.

Procomm Plus version 2.01, a commercial data communications package, is used to configure the modem, set up communications parameters, and establish a link with the remote modem. Procomm Plus includes a macro language called ASPECT, which allows the user to write and compile scripts which implement custom file transfer protocols. A simple ASPECT script was written to read the contents of a program file and upload it to the remote programmer.

The file transfer protocol (FTP) implemented is a simple send-and-wait, packet-oriented protocol. The transmit and receive modes of the FTP are illustrated by the flowcharts in figures 4 and 5, respectively. The transmitter sends each packet without flow control and waits for a response. The programmer (the receiver) reads and dissects the packet while calculating a checksum. If the calculated checksum is valid, the programmer acknowledges the packet by sending an ACK. If the checksum is in error, the programmer negatively acknowledges the packet by sending a NAK. Upon receipt of an ACK, the transmitter sends the next packet. If the transmitter receives a NAK, it resends the same packet. Transmission proceeds in this manner until the entire file has been transferred.

The programmer might respond to a packet by sending a CAN, which indicates that a non-recoverable error has occurred and that the transmitter should immediately abort the file transfer. If the programmer fails to respond to a packet within a limited period of time, the transmitter will resend the same packet. The transmitter will continue to resend the same packet until a valid response is received or until the allowed number of attempts is exceeded, at which time the file transfer is aborted.

After each packet is received and validated by the programmer, the data contained in the packet is programmed into the AT89C51 controller in the application. After programming, the data is read back from the controller and verified against the received packet data. Successful verification indicates successful programming, causing the programmer to send ACK to the transmitter. If programming fails, the programmer sends CAN to signal the transmitter to abort the file transfer.

The simplicity of the FTP reduces the amount of AT89C51 program memory used in the programmer. The send-and-wait nature of the FTP allows inter-packet delays due to AT89C51 program and erase times to be easily absorbed. Support for program verification is transparent, requiring no explicit command or result codes, or additional data transfers.

The files which are uploaded to the programmer are created with the tools in the Intel MCS-51 Software Development Package for the IBM PC. Included in the package are the MCS-51 Macro Assembler, MCS-51 Relocator and Linker, and a useful utility, OH. OH converts an absolute 8051 object file to an equivalent ASCII hexadecimal object file.

The records in the hex file produced by the OH utility serve, unchanged, as the packets in the FTP described above; no service fields need to be added. The colon which begins each record serves as the packet signature field. The load address field serves as the packet sequence number. A checksum is provided as the last field in each record. Since seven-bit ASCII coding is utilized, the eighth bit of each byte is available to be used for parity checking.

Because the AT89C51 in the programmer does not utilize external data memory, necessary packet buffering must be done using internal RAM. Limited memory precludes the use of conventional FTPs which utilize packets of 128 bytes and larger. The hex packet format used in this application limits packet data fields to 16 or fewer entries, requiring little memory for buffering.

The ready availability of a utility for creating the packetized program file, combined with small packet size and adequate error checking, makes the hex packet format a near ideal solution for this application. A disadvantage is the use of ASCII, which requires each program data byte to be expressed as two hex characters. This demands that nearly twice as many bytes be transferred as might otherwise be required. This is not a severe limitation, however, since typical file transfer times are less than one minute. Overall, the simplicity of the custom FTP/hex packet format implementation outweighs the drawbacks.

Remote Station

The remote station in the test configuration consists of the display application and programmer circuits, described previously, connected to a Hayes-compatible, Prometheus

1200 baud modem. During normal operation, the application executes its internal program while the modem and programmer monitor the phone line for incoming calls.

After a call has been detected and a connection established, the programmer forces the application to suspend execution of its program. The new program is then downloaded and programmed into the AT89C51 embedded in the application. When programming is complete, the application is allowed to begin execution of its new program, and the programmer returns to monitoring the phone line for the next call.

The programmer powers up with its programming control outputs inactive, allowing the application to run normally. After configuring the modem to answer incoming calls, the programmer puts itself to sleep. The programmer will not disturb the application until a new program is to be downloaded.

The programmer controls the modem by sending ASCII command strings over the serial interface, to which the modem responds with Hayes-style ASCII numeric codes. The software is designed for use with Hayes-compatible modems, which includes the Prometheus ProModem 1200 used here.

The serial interface, through which the programmer connects to the modem, supports two handshaking signals, DTR and DSR. On power up, the programmer asserts DTR, to which the modem responds by asserting DSR. If the modem should fail to respond to any command, including the command to hang up, the programmer deasserts DTR, which forces the modem to drop the line.

The modem monitors the phone line while the programmer sleeps, waiting for an incoming call. When a call is detected, the modem answers and attempts to establish communication with the caller. If a connection is established, the modem sends a code to the programmer, waking it up. The programmer verifies the connect code and begins polling for a valid packet header.

Incoming packets must arrive fewer than thirty seconds apart, or the modem drops the line (hangs up) and the programmer returns to sleep, waiting for the next call. If the caller hangs up, the thirty second period must expire before another call will be answered. Calls incoming during the reset delay period are ignored.

If a valid packet header is received prior to the expiration of the reset delay period, the programmer will attempt to read and validate the incoming packet. At any time during packet reception, an invalid character, parity error or timeout during character reception will cause the partial packet to be declared invalid and discarded.

Two packet types are defined: data and end-of-file. A data packet contains five fields in addition to the packet header, one of which is a variable length data field. The data field contains program data to be written into the AT89C51 con-

troller in the application. The load address field contains the address at which the data is to be written. The end-of-file packet contains the same fields as the data packet, except that the data field is empty. This packet type has special meaning to the programmer, as explained below.

Any packet which contains an invalid record type, record length or checksum is invalid. Program data accumulated during the processing of an invalid packet is discarded. The programmer sends a NAK to the transmitter to signal reception of an invalid packet and resumes polling for a valid packet header.

Receipt of the first valid data packet causes the programmer to interrupt the application controller. The controller responds to the interrupt by abandoning execution of its usual program and displaying a message indicating that programming is taking place. If this is the first valid data packet since power was applied or an end-of-file packet was received, the programmer asserts the control signals necessary to erase the program memory in the application controller. The programmer then places the controller in programming mode.

The first and subsequent valid data packets are dissected as they are received and the data which they contain is programmed into the application controller at the address indicated in the packet load address field. After programming, the data is read back from the controller and verified against the received packet data. Successful verification indicates that programming was successful, causing the programmer to send ACK to the transmitter. The programmer then resumes polling for a valid packet header, subject to the thirty second reset delay.

If programming fails, the programmer sends CAN to signal the transmitter to abort the file transfer. The modem drops the line and the programmer returns to sleep, waiting for the next call. The application controller is left in programming mode, preventing it from executing the incomplete or invalid program which it contains.

It is important to note that invalid packets are NEVER programmed into the application controller. To do so would require that the program memory in the controller be completely erased before the error could be corrected, causing the non-recoverable loss of all previous program data.

Upon receipt of an end-of-file packet, the programmer returns its control outputs to the inactive, power on state, allowing the application controller to begin execution of the new program. The programmer then resumes polling for a valid packet header, subject to the thirty second reset delay.

If a valid packet is received prior to the expiration of the thirty second delay, another programming cycle begins, which can only be terminated by the reception of a valid end-of-file packet.

If the reset delay expires prior to the reception of a valid end-of-file packet, the modem will drop the line and the programmer will return to sleep, waiting for the next call. In this case, the application controller is left in programming mode, preventing it from executing its program. To return the application to normal operation, another call must be received, and a valid program file uploaded, terminated by an end-of-file packet.

Setting Up the Hardware

Local Station

Connect the IBM PC to the ProModem 1200 through one of the system COM ports. Connect the modem to an analog telephone line and set the modem switches as indicated below.

Switch settings:

1	ON
2	ON
3	OFF
4	ON
5	OFF
6	ON
7	OFF
8	OFF
9	OFF
10	OFF

Remote Station

Connect the display application/programmer to the second ProModem 1200 through the programmer serial port. Connect the modem to an analog telephone line and set the modem switches as indicated below.

Turn the modem on and apply power to the display application/programmer. The application will begin executing its program, if it contains one. The programmer will initialize the modem, as shown by the activity on the modem status indicators.

Switch settings:

1	ON
2	ON
3	ON
4	OFF
5	ON
6	ON
7	ON
8	OFF
9	OFF
10	OFF

Installing and Configuring Procomm Plus, Version 2.01

Install Procomm Plus as instructed in the User Manual. When prompted to specify the modem in use, select 'Prometheus ProModem 1200' from the list.

Run Procomm Plus and create a dialing directory entry for the remote station. The baud rate must be set to 1200, parity to EVEN, number of data bits to 7, number of stop bits to 1, plex to HALF.

Enter the Setup utility (ALT-S). Select 'PROTOCOL OPTIONS', then 'EXTERNAL PROTOCOL OPTIONS' from the menus and modify the entry for 'EXTERNAL PROTOCOL 1' as indicated below.

EXTERNAL PROTOCOL 1:

A - NAME:	<any name>
B - TYPE:	ASPECT
C - UPLOAD COMMAND:	ATX.ASX

Note: 'ATX.ASX' is the filename of the compiled ASPECT script to be associated with External Protocol 1.

Save the changes and exit the Setup utility.

Creating a Hex File

The hex files which are uploaded to the programmer are created with the tools in the Intel MCS-51 Software Development Package for the IBM PC. In the example below, the 8051 assembler source file is called 'TEST.ASM'.

Assemble the source file 'TEST.ASM' and create the object file 'TEST.OBJ':

ASM51 TEST.ASM

Link and locate the object file 'TEST.OBJ' and create the absolute object file 'TEST.ABS':

RL51 TEST.OBJ TO TEST.ABS

Convert the absolute object file 'TEST.ABS' to the hex file 'TEST.HEX':

OH TEST.ABS TO TEST.HEX

The resulting file, 'TEST.HEX' is ready to be uploaded.

Note: ASM51 is version 2.3; RL51 is version 3.1; OH is version 1.1.

Uploading a Hex File

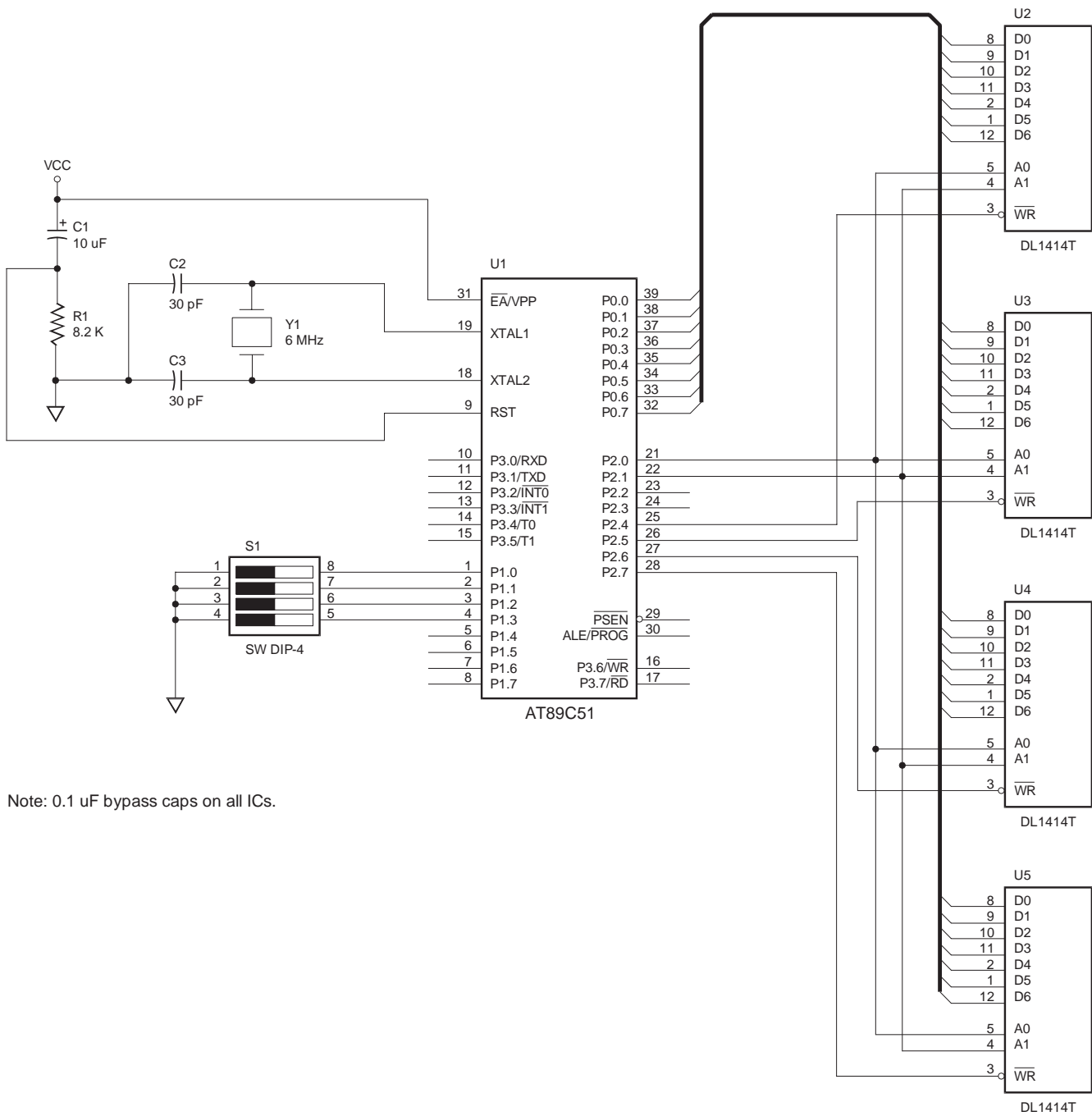
Run Procomm Plus and use the proper dialing directory entry to dial the remote station.

After the connection with the remote station is established, press the 'PgUp' key and select '1' (External Protocol 1) from the menu of upload protocols. This will execute the ASPECT script associated with External Protocol 1.

When prompted, enter the name of the file to be uploaded, including the extension and path, if required.

When the upload is complete, press ALT-H to hang up and ALT-X to exit Procomm Plus and return to DOS.

Figure 1. AT89C51 Moving Display Application Example



Note: 0.1 uF bypass caps on all ICs.

Figure 2. AT89C51 Moving Display Application Modified for In-Circuit Programming

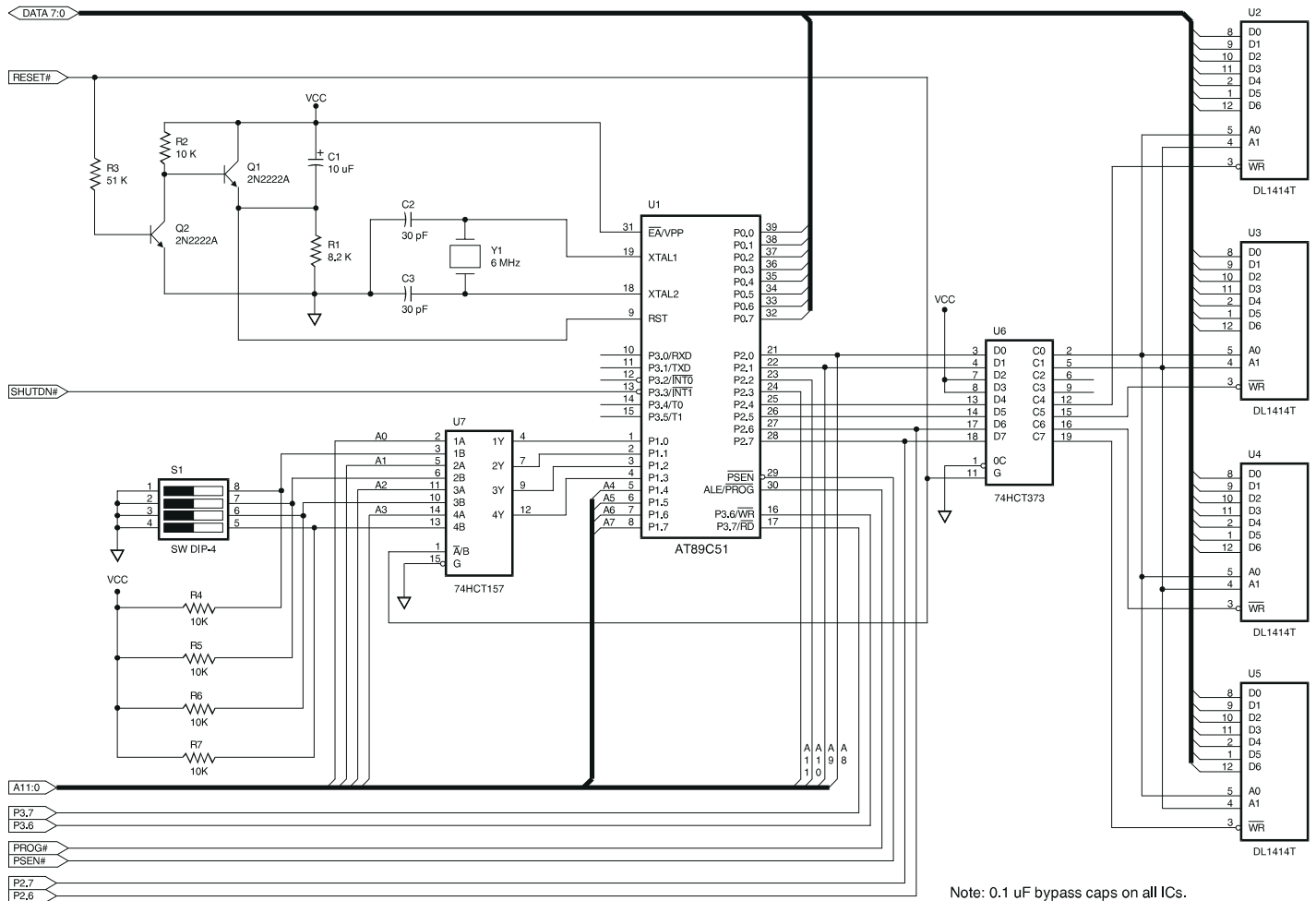


Figure 3. AT89C51 Programmer

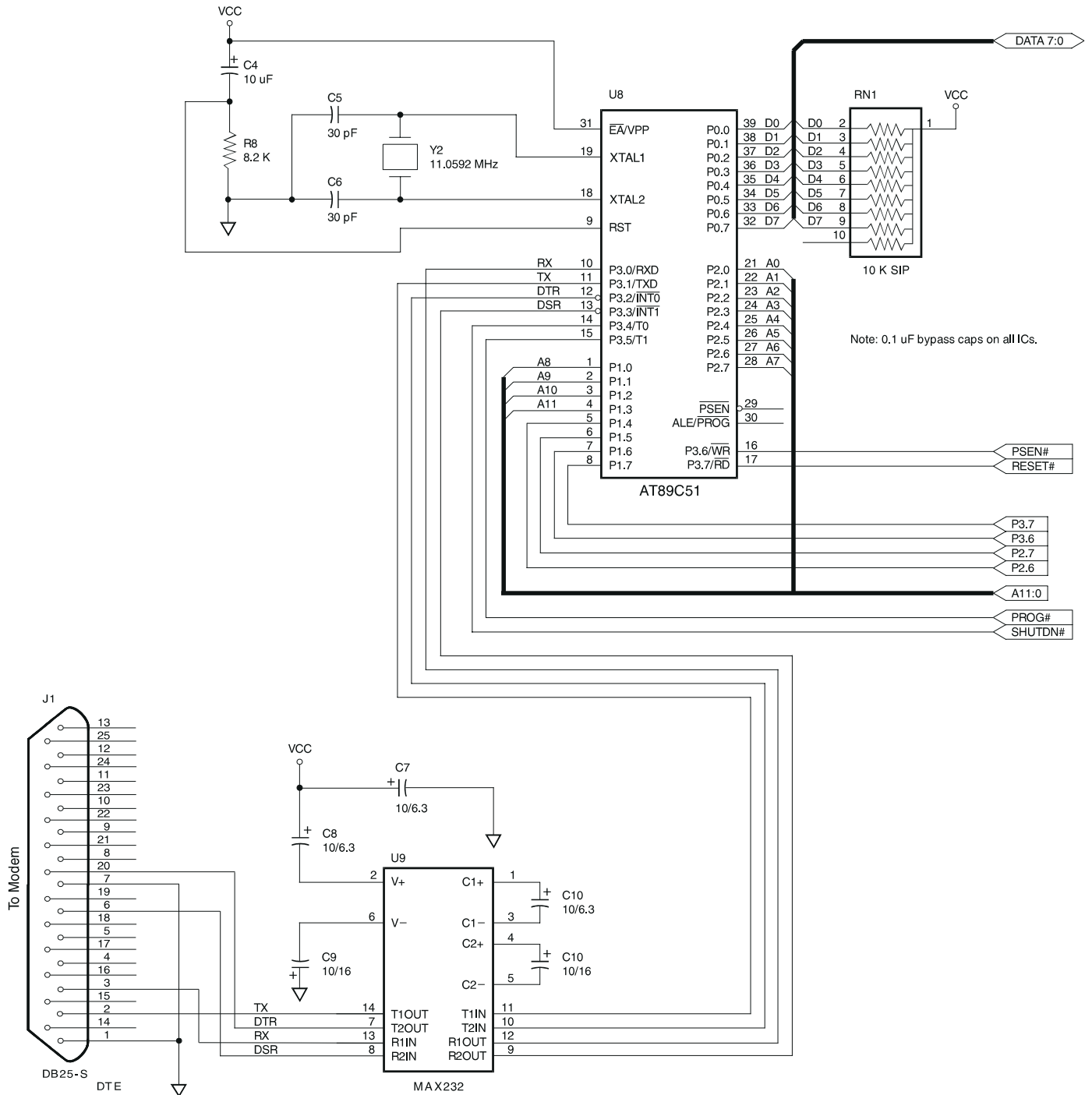


Figure 4. FTP Transmit Mode

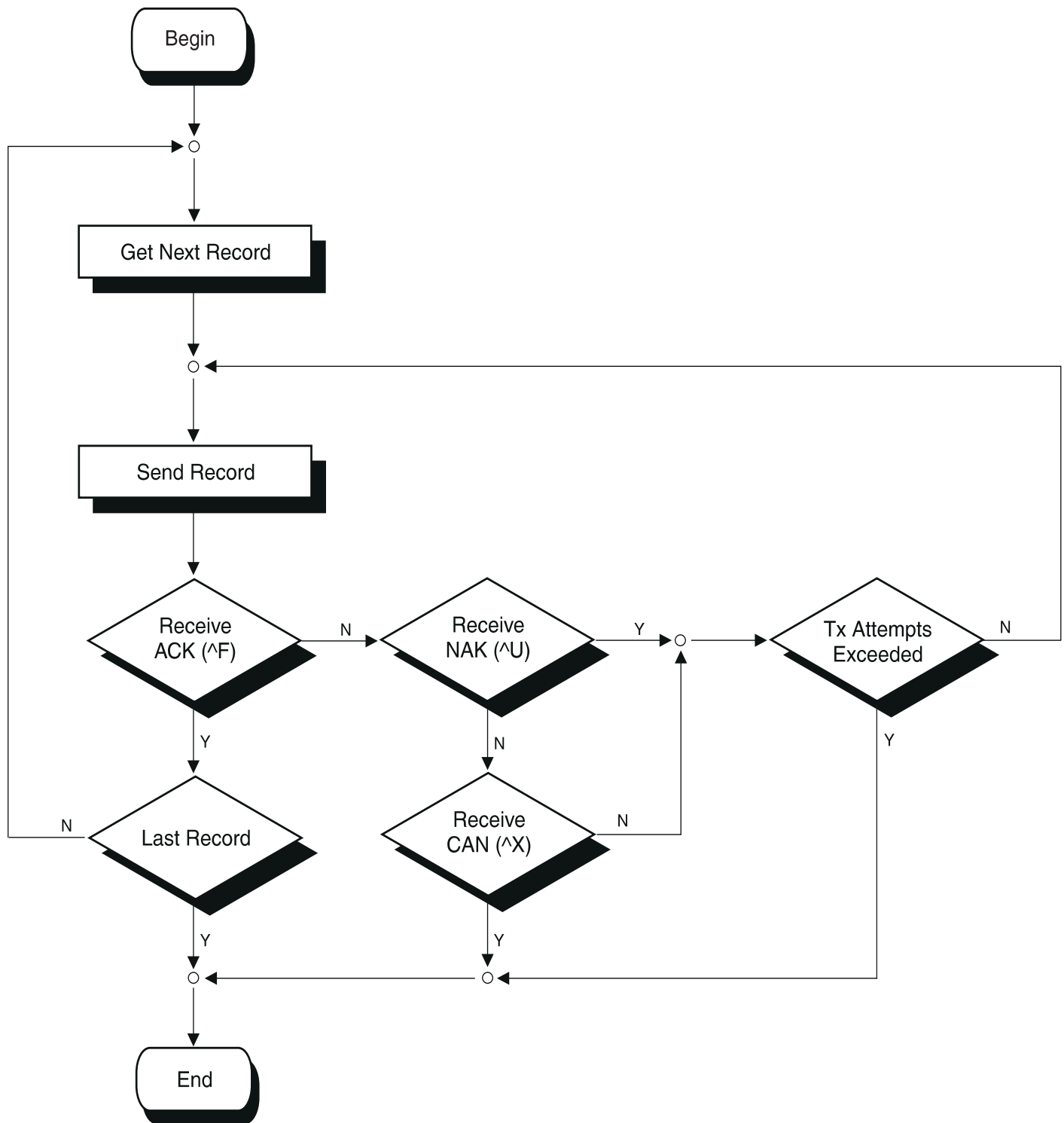
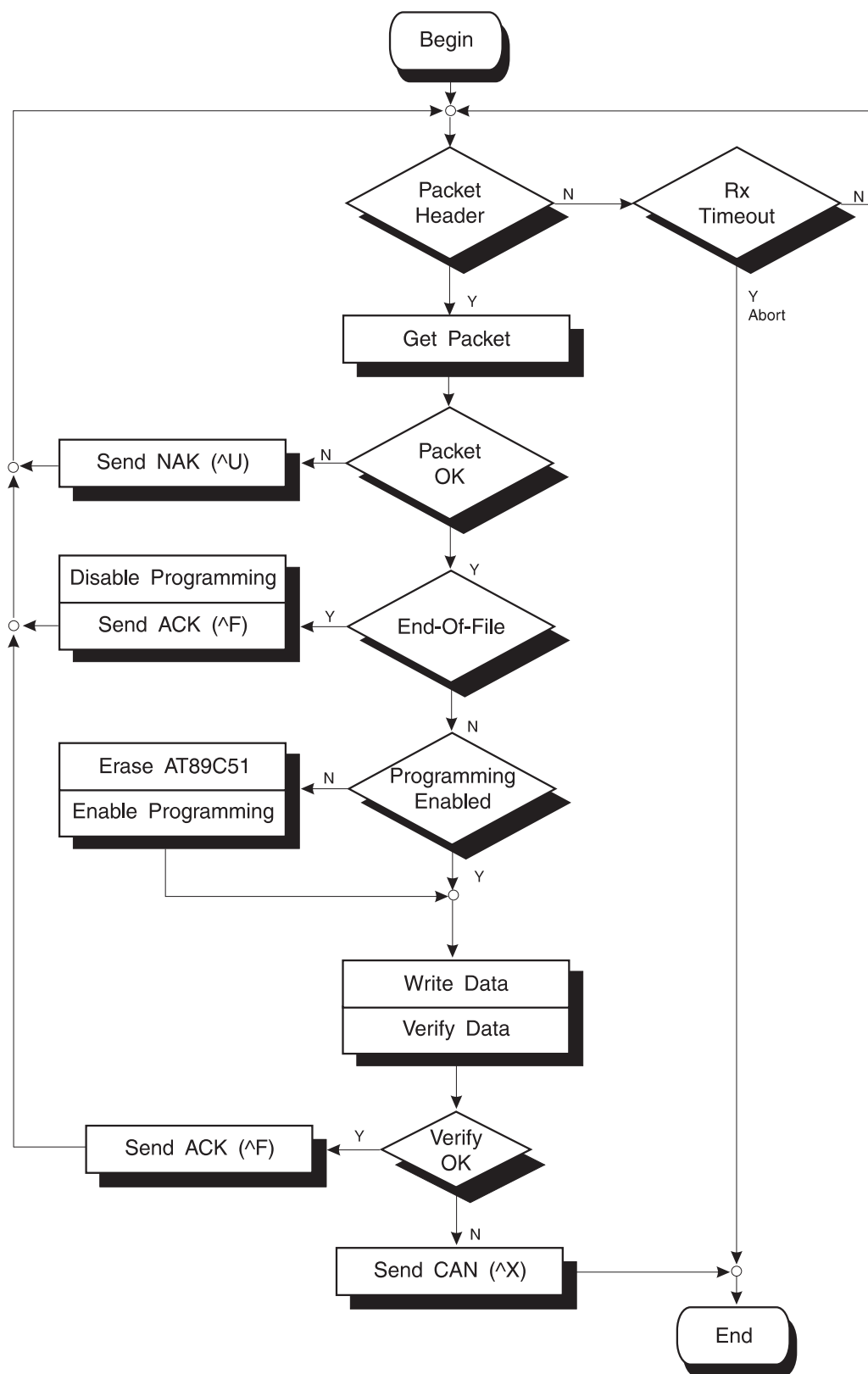


Figure 5. FTP Receive Mode



Appendix I: Intel Hex File Definition

Hexadecimal object file format (Intel hex) is produced by most 80C51 assembler products.

Each record in the file contains the following fields:

<:><rec length><load address><rec type><data><checksum>

The colon is the record header.

The record length field consists of two hex digits, and represents the number of entries in the data field. OH outputs records containing 16 or fewer data field entries.

The load address field consists of four hex digits, and indicates the absolute address at which the data in the data field is to be loaded.

The record type field consists of two hex digits, which are always zero in data records.

The data field contains from one to 16 pairs of hex digits.

The last two hex digits are a checksum on the record length, load address, record type, and data fields. The sum of the binary equivalents of these fields and the checksum itself is zero.

Each record in the file is terminated by a carriage return and line feed.

A type one record marks the end of the file. The record always contains the following value: ':00000001FF'.